Effects of Climate Change on the Dutch Rhine Branches

The Dutch are concerned with the consequences of accelerated sea level rise for the coastal protection system. **Astrid Blom** reminds us that climate change will not only affect the coast but also the rivers. PhD candidate **Claudia Ylla Arbos** will study these implications in further detail in the research program Rivers2Morrow of the National Research and Innovation Programme on Water and Climate (NKWK), funded by Rijkswaterstaat and DGWB.

The Rhine River is decreasing its channel bed slope

Over many decades the upper Dutch Rhine has been incising at a rate of about 2 cm/year. This channel bed erosion results from a decrease of the equilibrium channel bed slope and the associated tilting of the river profile around its downstream end. The decreased equilibrium slope is a response to mainly the river training of the past few centuries, which consisted of extensive channel narrowing due to the construction of levees and groynes. In fact, a narrower channel requires a smaller slope to transport the same amount of sediment supplied from upstream. The smaller equilibrium slope together with a tilting of the channel around its downstream end leads to channel bed incision. For more detailed information about these mechanisms, see the DeltaLinks article **Bed degradation in the Rhine River** by Astrid Blom.

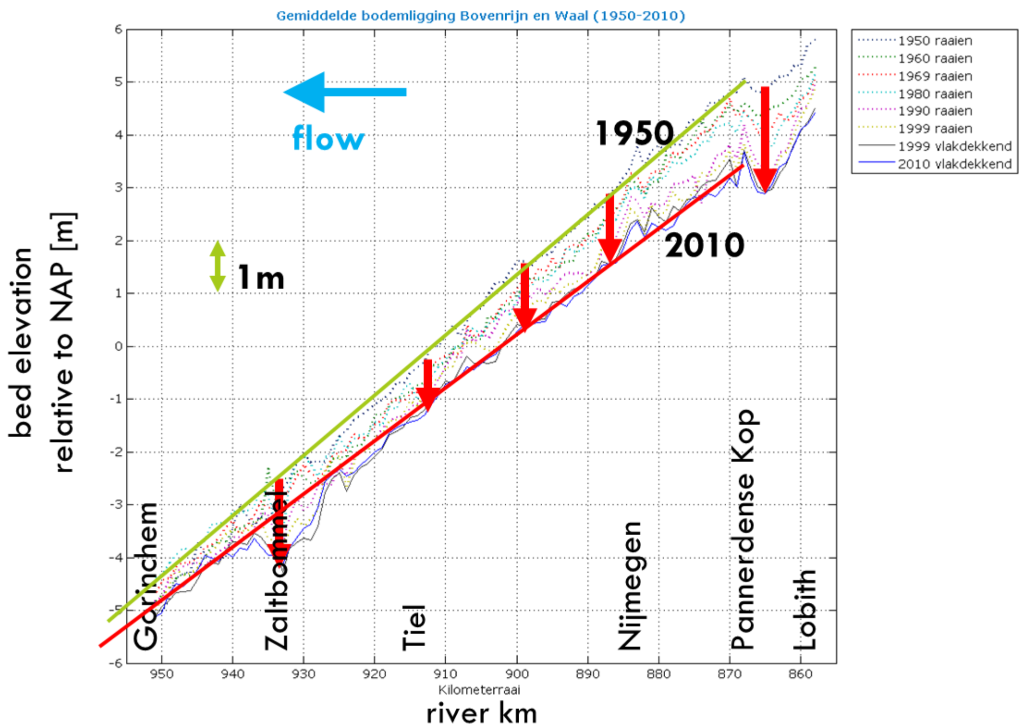

Figure 1

Decrease of channel slope in the Bovenrijn and Waal over a period of 60 years.

The rate of channel incision in the upper Dutch Rhine (about 2 cm/year) is one order of magnitude larger than the current rate of sea level rise (about 3 mm/year). The main problem associated with the channel bed incision is its spatial variation: reaches or obstacles that are barely or not eroded (e.g., Nijmegen, St. Andries, Erlecom) increasingly stick out from the bed. This more and more reduces the maximum draught of vessels during low flow rates and thus the amount of cargo that can be transported, which has significant economic consequences.

Another problematic aspect is the difference in incision rate between the downstream branches of the bifurcation Pannerdense Kop (i.e., the Pannerdensch Kanaal and the Bovenwaal). This different incision rate causes the partitioning of the water and sediment discharge over the downstream branches to slowly adjust and change with time. This affects flood safety of the downstream branches, as the level of protection is designed according to a certain partitioning of the water discharge between the downstream branches.

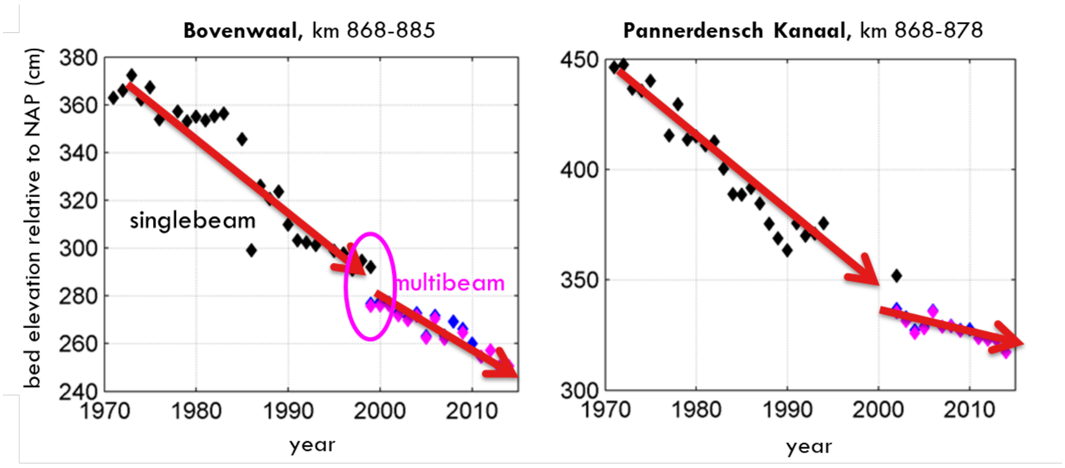

Figure 2 Bed level trend in Bovenwaal versus Pannerdensch Kanaal. The bed level discontinuity around 2000 is caused by a change in the measurement technique (singlebeam to multibeam).

Other problems associated with the channel bed incision are destabilization of structures, an increased risk of failure of cables and pipelines due to a reduced depth of soil cover, a decrease of the floodplain groundwater level with related effects on ecology and agriculture, and an increased disconnection between channel and floodplain.

Channel incision is associated with a difference between the sediment supply rate from above and the local sediment transport rate. A mitigating measure that compensates for bed degradation is sediment nourishment. German water authorities have successfully reduced or mitigated channel incision in the German Rhine through repeated and extensive sediment nourishments since 1978. In the Netherlands, Rijkswaterstaat has started to add sediment to the Bovenrijn reach in 2016 as part of a pilot field project. The pilot project enables an assessment of how sediment nourishment best helps in mitigating the channel bed incision. Yet we need a longer data record to draw conclusions regarding the measure's effectivity and follow-up.

The Rhine River is coarsening its bed surface rapidly
Despite being characterized by channel bed incision for decades, it is interesting to note that the Bovenrijn branch has stopped incising. Its mean bed level has been more or less constant over the last 30 years.

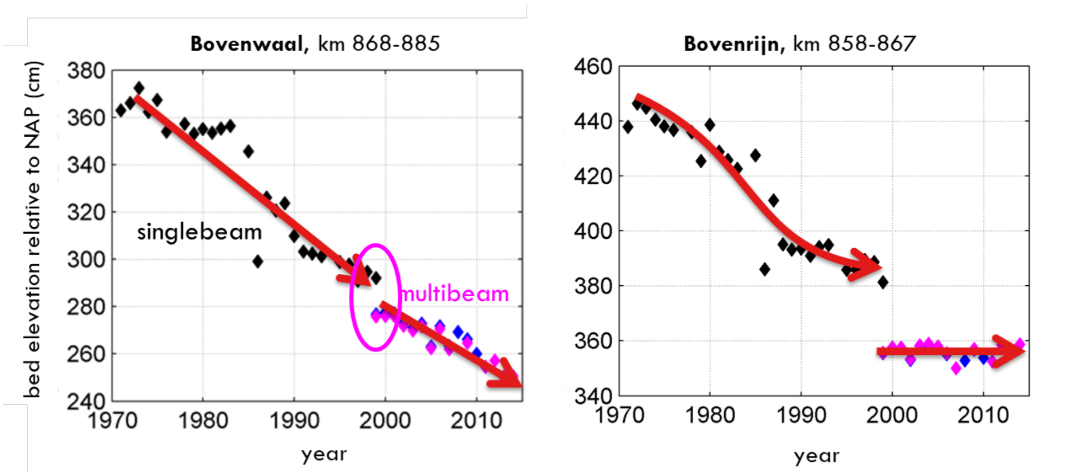

Figure 3 Bed level trend in Bovenwaal versus Bovenrijn. The bed level discontinuity around 2000 is caused by a change in the measurement technique (singlebeam to multibeam).

Besides channel slope (or bed level), also the grain size distribution of the bed surface sediment typically responds to changes in the controls. The median grain size of the bed surface sediment in the Bovenrijn has increased from 1 to about 10 mm within a period of only 20 years (between 1995 and 2016). This is an unprecedentedly rapid change. The stabilization of the mean bed level in the Bovenrijn seems to be related to this coarsening of the bed surface sediment. The latter seems to be induced by a downstream migrating coarsening wave.

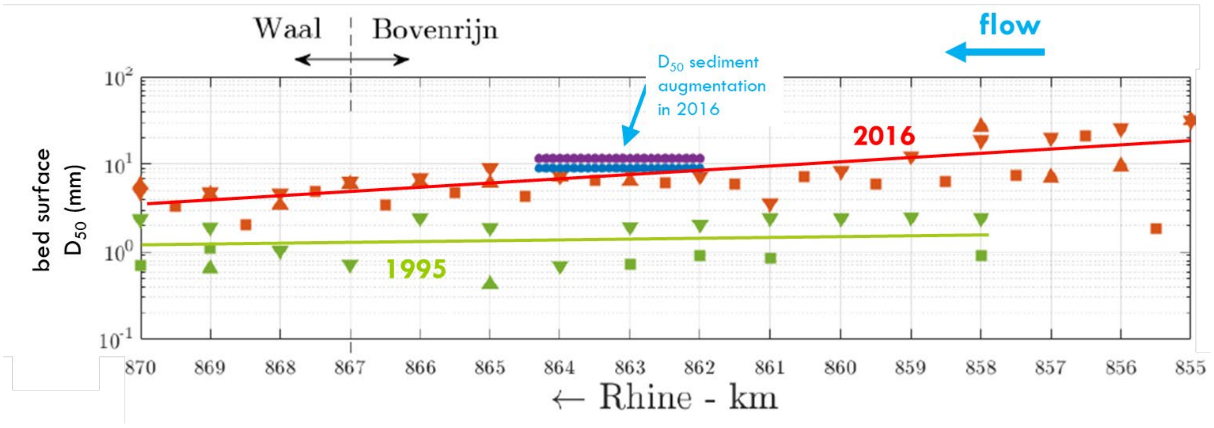

Figure 4 Rapid coarsening of the bed surface sediment.

Hence, the Bovenrijn has become a gravel-bedded river within a period of merely 20 years. Important questions here are the following: what are the causes of the coarsening wave; does the coarsening wave proceed further downstream, at what pace does the wave migrate downstream; what are the implications of the bed surface coarsening regarding channel incision; what are the implications of the channel incision and surface coarsening regarding the key river functions flood safety, navigation, and ecology; and how does the coarsening interact with the effects of climate change?

Climate change affects the Dutch Rhine branches

Climate change affects the Dutch Rhine branches through four changes of the controls: (1) (accelerating rate of) sea level rise; (2) a decrease of summer low flow rates; (3) an increase of winter peak flow rates; and (4) an increase of the duration of low flow periods.

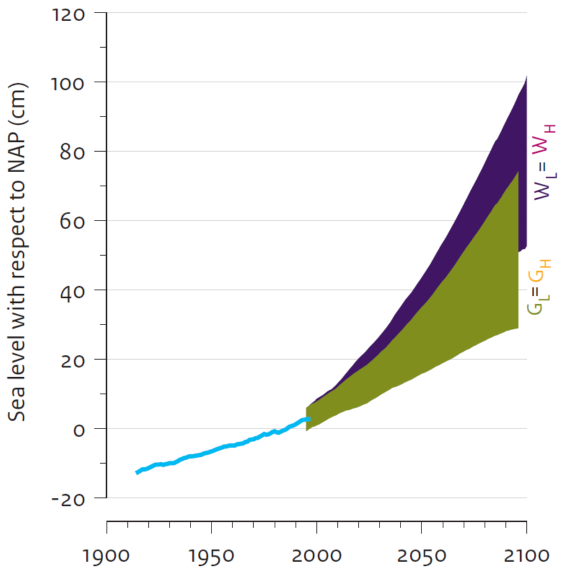

Figure 4 Observed sea level at the Dutch North Sea coast and the projections in the KNMI'14 scenarios. From KNMI (2014).

It is often mistakenly believed that the effect of the downstream water level (sea level and its increase) is limited to the river's backwater reach. However, due to the associated decrease of the flow velocity, sea level rise leads to additional sediment deposition in the downstream part of the delta, which results in an aggradational adjustment wave that migrates upstream. For instance, after 25 years of sea level rise at a rate of 3 mm/year, the rate of water level rise at a position 100 km upstream from the river mouth equals 1 mm/year. The rate of water level rise at this upstream position increases with time, with a maximum rate of 3 mm/year. These effects, however, may become more serious, as the rate of sea level rise is expected to increase with time.

The equilibrium river channel geometry (regarding slope and bed surface grain size) is not expected to be strongly influenced by the extreme values of winter peak flows and summer low flows, since these extreme conditions prevail over a very limited fraction of time, and the low summer flow rates are characterized by limited morphodynamic activity. The upstream migrating aggradational adjustment wave associated with sea level rise counteracts the ongoing channel bed incision, but it raises the peak flow water level and thus increases flood risk.

The higher winter peak flow rates increase flood risk, whereas the further decrease of the low summer flow rates mostly hinders navigation and freshwater intake, and even more so as the duration of the low flow periods increases. The longer duration of the low flow periods also intensifies the problems associated with desiccation of the floodplains.

It is mostly the combination of the (a) current channel bed incision, (b) nonerodible reaches that increasingly stick out from the bed, and (c) longer periods of extremer low flow rates that will be an ever larger burden to navigation. The long period of low flow in the summer and fall nof 2018 well illustrates the consequences for navigation, with possible risk of a modal shift away from inland shipping.

Nature-based solutions
Rijkswaterstaat currently combats the channel bed incision through sediment nourishments near Lobith. Similar to the Sand Engine near the coast, these nourishments can be considered nature-based solutions, as the term nature-based solutions refers to the sustainable management and use of nature for tackling socio-environmental challenges. Sediment nourishments may be considered a nature-based solution, as one benefits from the (transport) capacity of the river to disperse the locally dumped sediment.

In order to be effective, sediment nourishments have to be repeated with a certain frequency, have to be conducted at various positions along the channel, and the grain size distribution of the added sediment needs to be carefully chosen. Adding sediment that is coarse compared to the bed sediment even enhances (rather than counteracts) the degradation problem in the downstream reach, as a result of the associated decrease of the local sediment transport capacity.

NKWK Rivers2Morrow program
This Flows article sets the context of the PhD research project by Claudia Ylla Arbos, who has started with her research project on 1 December 2018. Her research project is part of and funded by the research program Rivers2Morrow of the National Research and Innovation Programme on Water and Climate (NKWK, *Nationaal Kennis- en innovatieprogramma Water en Klimaat*)
. The NKWK programme is funded by the Directorate-General for Rijkswaterstaat and the Directorate-General for Water and Soil (DGWB), both part of the Ministry of Infrastructure and Water Management. In the next few years, Claudia Ylla Arbos will study the above aspects in further detail. Her PhD research project will contribute to achieving a resilient Rhine-Meuse delta.

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